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Final Technical Report for ONR Contract N00014-88-K-0172

15 November 1987 - 14 November 1991 (California University, San Diego, La Jolla. Department of Physics).

Dear Mohsen,

This letter constitutes the final report for ONR contract N00014-88-K-0172 covering the period Nov. 15, 1987 to Nov. 14, 1991. The necessity of this report is due to the fact that in November of 1991 the ONR contract that I had held for some 15 years was changed to a grant. Since you have all of my annual technical reports and all of the research has been published, I will simply give a brief descriptive summary of the work done in those four years.

Scattering from Rough Surfaces

In 1987 and 1988, Dan Wurmser (now at NRL) and I developed a new method for scattering from rough surfaces. There were several new results. The first was a new exact formula for the scattering amplitude which manifestly exhibits reciprocity. However, like all exact formulas it is useful only in conjunction with numerical work. On the other hand, this new formulation of the scattering problem lead to an approximate expression for the scattering amplitude which is no more difficult to apply than the Kirchoff approximation and is much more accurate. In fact, this new approximate expression is valid whenever one can argue that a two scale approach makes sense, i.e. when there is small scale roughness superimposed on top of a smooth large scale structure. This work provided a formal, exact statement of the two scale approximation which includes perturbation theory and the Kirchoff approximation as special

cases. These ideas are currently being used to solve a practical problem in a classified navy program.

A variant of this work was used by Wurmser, Henyey and myself to show that, contrary to opinion at that time, the enhanced cross sections seen in acoustic backscatter from the sea surface could not possibly be due to scattering from ocean waves. Now, of course, we know that the enhanced scattering is due to bubbles but at that time there was considerable debate.

Renormalization of Rough Surfaces

In 1987 I set out, with a student, Greg Orris, to understand the effects of random structures on scales smaller than a wavelength. That work continued until Orris finished his PhD in 1991. Orris is now a staff member at NRL.

The folklore is that scales smaller than a wavelength do not have a significant effect on scattering from a rough surface. Greg and I found that this is not generally true and is definitely not true when the roughness has a power law spectrum with an exponent less than or equal to two. (Sea surface roughness has a exponent of about two.) We developed a renormalization group approach that allowed us to "integrate out" the small scales, replacing them with an effective surface impedance that depends on the wavelength of the incident radiation.

Although the formalism has been developed and the results documented and published, I do not consider this problem finished. I do not have a good intuitive feel for what we found and there are many unanswered questions. I hope to have a future student do more work on the problem.

As a side issue, our work on renormalization lead to a proof that the perturbation expansion for scattering from a rough surface with a pure power law spectrum cannot converge. Beyond a (calculable) point the coefficients in the expansion themselves become divergent.

Propagation in Random Media

In 1987, I began some work on propagation in random media together with a student Guan Yu Wang, now with Stan Flatte at UCSC. Wang's first project was to implement an old idea of mine that in the strong scattering regime the wave function can be represented by an object that satisfies complex gaussian statistics times another factor which is essentially log normal. Wang was able to work out the details and show that this is, in fact, true. The usefulness of this result stems from the fact that it allows one to work out the statistics of things such as

log amplitude or phase in the strong scattering regime, including the leading corrections to saturation. It also allows one to determine whether or not the probability distribution function is asymptotically Rayleigh, Rayleigh convoluted with log normal, K distributed or something else. (I now know that it is something else, where the something else is not universal and varies from problem to problem.) This work has all been documented and published.

When Wang and I compared some of our results to numerical simulations by Flatte, we discovered that the theory did not seem to be approaching its asymptotic limit nearly as fast as we had expected. An investigation of this problem lead to a significant breakthrough in the study of propagation through random media with a power law distribution of scale sizes. (Ocean acoustics corresponds to this situation with a power law of about two.)

It turns out that for power law exponents, p, close to two the asymptotic expansion converges much more slowly than anyone had expected. This is quite unfortunate because most real applications of the theory correspond to situations where p is close to two. However, Wang and I found that there is a rather simple way to reorder the asymptotic series so that convergence is much more rapid. This allowed us to calculate many things of experimental interest which had never been theoretically tractable, either analytically or numerically.

This work has been published for about six months now and constitutes a breakthrough in propagation in random media. In its current state, it is of immediate practical use in atmospheric optics, propagation of electromagnetic waves through the ionosphere and short range high frequency ocean acoustics, three problems of direct interest to the Navy. It is also applicable to long range ocean acoustics but some more work is required to bring in the sound channel effects. This is currently being done at UCSC.

Scattering from Planar Objects

The new scattering formalism developed with Wurmser leads, when applied to scattering by planar objects, to a remarkable result. It gives an exact formula for the scattering amplitude in terms of a line integral around the edge of the scatterer. The integrand is the coefficient of the singularity in the wave function at the edge of the planar object. (The exact solution of the wave equation in the presence of a thin planar scatterer has a square root singularity at edge of the scatterer.) Useful approximations can be obtained by approximating the integrand by the solution to a local half plane problem.

Some of the work on this problem was done prior to 1991 but many further results have been obtained in the last two years. It

constitutes the thesis research of Ahmed Abawi who is currently choosing between postdoc offers from NRL and NRAD. Ahmed's thesis has been deposited and a series of four papers on this problem are nearly completed.

The main results of the last two years have to do with the effects of sharp corners. Applications of the formalism will include object recognition in radar and sonar as well as stealth, either electromagnetic or acoustic.

Coastal Effects in Low frequency Acoustics

Walter Munk and I worked out the acoustic field of a deep water source refracted by a coastal slope. It is essentially a problem of matching deep water propagation to the wedge solution near the coast. We found a number of interesting things including a previously undiscovered coastal caustic. The existence of this caustic has since been verified by numerical calculations.

A paper was written and submitted but needs to be rewritten. Unfortunately, work on this project was halted two years ago by serious medical problems on the part of both of our wives. We have committed some time this fall to rewriting the paper.

As you can see the period 1987-1991 was an interesting time. I hope that this letter, together with my annual reports and publications will provide adequate documentation.

Sincerely yours,

Roger Dashen

Roger Dashen